HUMAN RISK TO OCEAN ACIDIFICATION

Photo credit: NOAA

ABSTRACT: Ocean acidification is a global phenomenon generated from increased anthropogenic carbon dioxide emissions. Increased rates of ocean acidification are projected to drastically alter marine and coastal ecosystems. Human communities are intrinsically linked to ocean acidification, both as the main drivers of the process and as a particularly vulnerable party to its expected effects. As part of a larger project that aims to highlight global hotspots of vulnerability to ocean acidification, this paper explores the concept of characterizing and measuring the socioeconomic, cultural, and political forces that influence human vulnerability. This paper offers a concise overview of vulnerability, sensitivity, and adaptive capacity as they relate to ocean acidification, and provides a comparison of five vulnerability studies to explore commonalities between vulnerability framework methodologies. This paper also provides a detailed review of the collection and initial analysis of variables considered in determining which human communities are most at risk from ocean acidification.

KEYWORDS: ocean acidification; vulnerability; adaptive capacity; sensitivity; adaptation; characterization; framework; resilience.

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INTRODUCTION

For the past decade, climate change has taken center stage in a contentious international dialogue riddled with buzzwords like “emissions reduction requirements”, “mitigation efforts”, and “adaptive solutions”. The focus of these dialogues is essential and deserves continued attention, but there is something missing from the conversation: ocean acidification. Ocean acidification is a chemical process by which atmospheric carbon dioxide dissolves in seawater and reduces its pH and carbonate ion levels (Feely et al. 2008; Feely et al. 2012; Doney et al. 2009). Increased rates of ocean acidification are predicted to seriously impact many of the world’s coastal and marine species and the communities, both ecological and human, which depend upon them (Doney et al. 2009; Cooley et al. 2006).

Research to date has rapidly advanced our understanding of the biogeochemistry of ocean acidification, but little research has questioned which human communities are most at risk from the impacts of ocean acidification. Human communities are intrinsically linked to ocean acidification, both as the main drivers of the process and as a particularly vulnerable party to its expected effects. The impetus to address the human dimension of ocean acidification suggests the need for an integrated, interdisciplinary approach to research, analysis, and policy development. Understanding how ocean acidification affects economically important species and where these ecological changes are expected to harm human communities the most is a critical step in moving towards focused, actionable climate change and ocean acidification policies.

PROJECT OVERVIEW

This Master's Project is focused on the human dimension of ocean acidification and explores the topic of vulnerability and adaptive capacity.

The four objectives of this Master's Project are to:

1. Provide a concise overview of vulnerability and adaptive capacity as they relate to ocean acidification;
2. Compare and contrast the methodologies of recently published vulnerability studies;
3. Prepare a detailed overview of the data collection and analysis methodologies for the adaptive capacity component of the larger project; and
4. Perform the initial analysis of the metrics and indicators used in the adaptive capacity component of the larger project, as detailed below.

This project is an extension of a larger collaborative project funded and organized by the National Science Foundation's National Socio-Environmental Synthesis Center (SESYNC). The project, entitled, "Using Spatial Data and Analysis to Understand and Manage the Human Cost of Ocean Acidification", is broad in scope and convenes a wide range of experts working in the field of ocean acidification. The primary goals of this project are to synthesize oceanographic data, ecological data, and socioeconomic data to identify where ocean chemistry is changing most rapidly, where vulnerable marine species are located, and where people who depend on these species reside.

The principal investigators for the Ocean Acidification SESYNC team (OA-SESYNC) include: Dr. Linwood Pendleton (Senior Scholar, The Nicholas Institute for Policy Solutions), Dr. Lisa Suatoni (Senior Scientist, Natural Resource Defense Council), Dr. Sarah Cooley (Woods Hole Oceanographic Institute), Dr. Julia Ekstrom (Science Fellow, Natural Resource Defense Council), and Dr. Will McClintock (Project Scientist, University of California Santa Barbara Marine Science Institute).

CONCEPTUAL FRAMEWORK

The collaborative project is organized from a conceptual model based on the IPCC's *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX) (2012). Dr. Julia Ekstrom, a principal investigator for the OA-SESYNC team, adapted the SREX model to create a conceptual model (Figure 1) that explores the three components of disaster risk as they relate to ocean acidification.

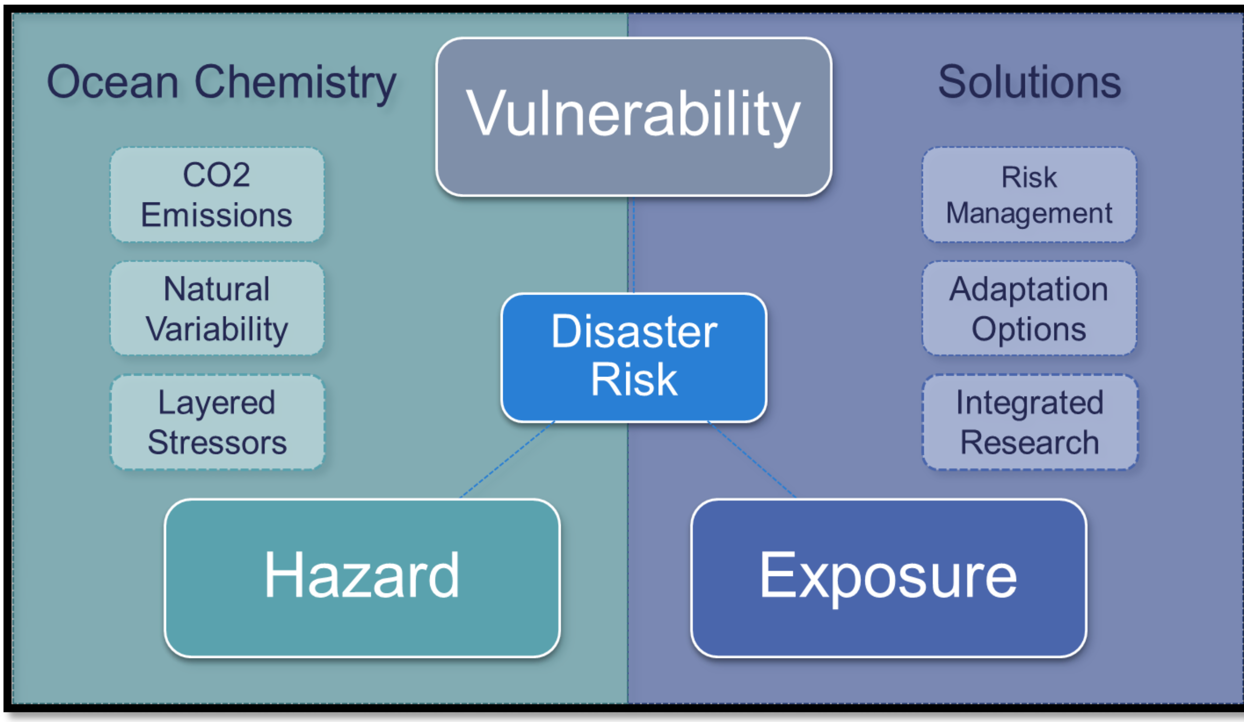

Figure 1. Ocean acidification conceptual model.
This model connects the three components of ocean acidification: hazard, exposure, and risk. Adapted from the SREX conceptual framework for risk assessment (IPCC 2012).

HAZARD

The ocean is a "sink" that absorbs excess atmospheric carbon dioxide in a natural and ongoing chemical process called ocean acidification (Feely et al. 2008). However, the current rate of ocean acidification is almost ten times faster than all previous rates in the past 50 million years (Feely et al. 2012). Increased rates of ocean acidification are the ***hazard*** for this study.

The primary drivers of this increase are human activities like burning fossil fuels and changing land uses. In fact, according to the Intergovernmental Panel on Climate

Change, the ocean has absorbed approximately forty percent of carbon dioxide produced by human activities over the past two centuries (IPCC 2007; Brander 2010; Cooley et al. 2006; Cooley & Doney 2009).

As human-generated atmospheric carbon dioxide levels continue to increase, the precise geochemical equilibrium of the oceans and atmosphere is compromised in two ways: (1) the ability of the ocean to absorb carbon dioxide decreases, and (2) the fundamental chemical composition of the oceans is altered as ocean pH and availability of essential ions and minerals declines (Doney et al. 2009; Doney 2010; Feely et al. 2012).

Further, literature acknowledges that rates of ocean acidification are regionally variable and reflect the varying physical and biological elements of coastal and marine ecosystems (Kelly et al. 2011; Narita et al. 2012). Local sources contribute to changes in coastal and marine chemistry, but current scientific assessment lacks specific interpretation of the interactive effects of ocean acidification with other climate variability implications (i.e. increased ocean temperatures and sea levels), as well as other human-driven stressors like marine pollution, overfishing, coastal nutrient inputs, habitat destruction, and invasive species (Brander 2010; Cooley & Doney 2009; Doney 2010; Sumaila 2011; Kelly et al. 2011).

In this study, hazard is represented as a function of predicted changes in aragonite concentration, as well as proxies that denote current local conditions of coastal habitats.

EXPOSURE

This study documents the distribution of two kinds of organisms - shellfish and corals - that will be harmed by ***exposure*** to increased rates of ocean acidification. This study focuses on shellfish and coral reefs because these organisms are known to be sensitive to changes in ocean chemistry and also have quantifiable social and economic value.

Increased rates of ocean acidification are predicted to drastically alter marine and coastal ecosystems across the globe (Brander 2010; Cooley et al. 2006; Cooley & Doney 2009). As the ocean absorbs atmospheric carbon dioxide, chemical reactions occur that reduce carbonate ion concentration, resulting in a reduction of pH and an increase in acidity (Feely et al. 2008; Feely et al. 2012; Kleypas et al. 2006). Carbonate ions are essential minerals that many organisms - called calcifiers - use to build shells and skeletons (Doney et al. 2009; Kleypas et al. 2006; Orr et al. 2009). The chemically corrosive conditions of ocean acidification can compromise a variety of life history characteristics, including the physiology, behavior, growth, reproductive capacity, mortality and distribution of organisms like oysters, clams, scallops, mussels, abalone, geoducks, sea urchins, some species of seaweed, and sea cucumbers, among many others (Doney et al. 2009; Kleypas et al. 2006; Orr et al. 2009).

The effects of ocean acidification have broader implications for the marine environment. Many of these calcifying organisms play important ecosystem service roles providing shelter, habitat, and food sources for other marine and coastal organisms (Doney et al. 2009; Kleypas et al. 2006). As ocean acidification inhibits the growth of carbonate shells and skeletons, the negative impacts will cascade across entire ecosystems with the potential to force ecosystem shifts beyond the ecological “tipping point” (Cooley & Doney 2009; Cooley et al. 2006).

In this study, exposure is integrated into the assessment of risk and is calculated as a function of the global distribution and status of coral reefs and domestic (U.S.) distribution and status of shellfish communities.

VULNERABILITY

Though vulnerability is conceptualized in different ways by numerous scholarly disciplines, in the context of this study, ***vulnerability*** is defined as the degree to which human systems are likely to experience harm as a result of increased rates of ocean acidification (Turner et al. 2003; IPCC 2012; IPCC 2014; Adger 2006; Füssel 2007; Luers et al. 2003).

Recent research has advanced understandings of the biogeochemistry of ocean acidification, but pervasive uncertainty exists in projecting the possible implications of ocean acidification to human communities across local, regional, and global scales. Measuring and assessing human vulnerability, however, is becoming increasingly necessary as the implications of global issues like climate change become locally relevant (Hughes et al. 2012; Adger 2006).

With its origins in social science, the concept of vulnerability is emerging and dynamic; a broad spectrum of disciplines and traditions continues to explore the themes, methods, and concepts that define vulnerability (Adger 2006). Concisely described by Smit & Wandel (2006), “...the vulnerability of any system (at any scale) is reflective of (or a function of) the exposure and sensitivity of that system to hazardous conditions and the ability or capacity or resilience of the system to cope, adapt or recover from the effects of those conditions.” This definition links community vulnerability to exposure, though recent research separates vulnerability from exposure, as detailed in the SREX (2012) framework and the IPCC Climate Change Report (2014). Vulnerability is evaluated as a function of sensitivity and adaptive capacity, while exposure is integrated more directly into risk assessment (IPCC 2014; IPCC 2012).

Vulnerability is a phenomenon driven by complex, multiscalar, and dynamic processes (Adger 2006; Gallopín 2006; Brooks et al. 2005; Vogel et al. 2007; Füssel 2007). A community's vulnerability is influenced by both external and internal factors that include structure, processes and framework (Beck et al. 2012). As such, metrics to explore or measure vulnerability are difficult to find and even more difficult to evaluate (Adger 2006; Füssel 2007; Brooks et al. 2005; Haddad 2005; Hinkel 2011; Smit & Wandel 2006). Thus, many vulnerability frameworks employ a range of metrics that may characterize vulnerability when combined. Vulnerability analyses examine the underlying socio-economic, cultural, political, and institutional factors that influence how human communities prepare for, respond to, and cope with hazards like ocean acidification (Adger et al. 2004; Füssel 2007; Brooks et al. 2005; Smit & Wandel 2006; IPCC 2012). Vulnerability assessments are dependent upon the context of the scenario; the factors that influence vulnerability depend upon the nature of both the human system and the environmental hazard being considered (IPCC 2012; Brooks et al. 2005). It is important to note that vulnerability assessments are conducted for different purposes and goals and these goals often inform how the scenario is framed, as well as the information required to complete the vulnerability analysis.

The concept of vulnerability can be further explored through ***sensitivity***, which refers to a community's reliance or dependence upon the organisms exposed to the stressor, and ***adaptive capacity***, which represents the ability (or lack thereof) of a community to prepare for, respond to, cope with or recover from external stressors (IPCC 2012).

SENSITIVITY

The effects of ocean acidification are predicted to compound over time, beginning with losses of single species and ultimately forcing ecosystem regime shifts (Cooley & Doney 2009). In this study, ***sensitivity*** refers to human communities' reliance on shellfish or coral reefs and will be represented as a function of nutritional dependence, economic dependence, and ecosystem services.

Due to the scale of ocean acidification, economic valuation of the effects of ocean acidification is limited to small studies that focus on quantifying the impacts of ocean acidification on a single species or fisheries category. In a recent global scale assessment of ocean acidification, Narita et al. (2012) use global shellfish production and consumption to extrapolate the potential economic implications of ocean acidification on the global fisheries industry. The authors estimated that the global and regional costs of loss of mollusk production due to ocean acidification will total over USD 100 billion (Narita et al. 2012).

In terms of projecting the direct economic impacts of ocean acidification associated with fisheries, a study by Kite-Powell (2009) estimates tens of billions of dollars in costs to marine fishery production and reef ecosystems each year. Literature acknowledges that not only are these reef and shellfish communities especially vulnerable to climate-driven ecological regime shifts, they also serve as primary economic supports for coastal communities around the globe (Kleypas et al. 2006; Brander et al. 2009).

Scaling the impacts of ocean acidification from single species to ecosystems is difficult, but recent studies (Armstrong et al. 2012; Cooley et al. 2006) identify four main types of ecosystem services provided by ocean and marine resources to human communities that are susceptible to the effects of ocean acidification: (1) provisioning, as defined by commercial fisheries; (2) regulating, including coastal protection, carbon storage, water cycling; (3) cultural, as defined by spiritual and aesthetic values; and (4) supporting, including nutrient cycling, habitat, primary production.

After establishing a set of indicators to evaluate a community's sensitivity to the predicted implications of ocean acidification, a community's adaptive capacity must be considered.

ADAPTIVE CAPACITY

In conjunction with establishing a set of indicators to evaluate a community's sensitivity to the predicted implications of ocean acidification, a community's adaptive capacity must be considered. In this study, ***adaptive capacity*** refers to the ability of human systems to prepare for, respond to, cope with, or recover from changes in ocean chemistry (Adger et al. 2004; Adger & Vincent 2005; Adger et al. 2004; Brooks et al. 2005; Engle 2011; Gallopín 2006; Hinkel 2011). It is important to note that the processes that drive vulnerability, sensitivity, and adaptive capacity are interrelated and interdependent (Adger et al. 2004; Adger & Vincent 2005; Brooks et al. 2005; Engle 2011; Gallopín 2006; Smit & Wandel 2006).

The concept of adaptive capacity is rooted in organizational theory and sociology, but has evolved most recently to focus how human communities address global stressors like climate change (Engle 2011). Where vulnerability is a negative attribute for a human community, adaptive capacity is a positive attribute. The more adaptive capacity a community has, the more likely that community will be equipped to prepare for, manage, and recover from external stressors (Engle 2011).

Like vulnerability, adaptive capacity is difficult to characterize and even more difficult to explicitly measure (Smit & Wandel 2006; Adger 2006). Adaptive capacity is context-specific and highly variable over space and time (Engle 2011; Smit & Wandel 2006; Yohe & Tol 2002; Tol & Yohe 2007; Hinkel 2011). Adaptive capacity is an attribute inherent to a community, but it is not static. Adaptive capacity can be both improved upon and diminished (Gallopín 2006; Adger 2006; Hinkel 2011). The interaction of socioeconomic, cultural, and political forces influences adaptive capacity across scales (Engle 2011; Hinkel 2011; Smit & Wandel 2006).

The factors that influence adaptive capacity function across multiple scales, but can include fluctuating factors like access to financial, technological and information assets, infrastructure and institutions, governance and political influence, community relationships, and socioeconomic status, among others (Adger et al. 2004; Adger & Vincent 2005; Brooks et al. 2005; Engle 2011; Gallopín 2006; Smit & Wandel 2006; McClanahan & Cinner 2011). These drivers of adaptive capacity have been grouped by McClanahan & Cinner (2011) into four distinct categories (1) flexibility, which can be interpreted in terms of livelihoods and institutions; (2) assets, which provide communities with the resources to deal with system changes; (3) learning, which refers to a community's ability to recognize and mobilize resources to respond change; and (4) social organization, which refers to a community's ability to organize and act collectively.

The adaptive capacity indicators used in this study include a range of determinants and are explored in detail in the next section of this paper.

COMPARISON OF VULNERABILITY STUDIES

As described above, the methodologies for measuring adaptive capacity and sensitivity vary greatly and can include descriptive case studies, survey techniques, modeling, and mapping (Engle 2011). A majority of vulnerability frameworks estimate adaptive capacity by aggregating metrics and theoretical determinants of adaptive capacity in different ways, ranging from generic characteristics to very specific sets of information that is directly connected to the hazard (Engle 2001; Brooks et al., 2005; Smit & Wandel, 2006). To explore this further, the methodologies and results of five previously published studies are reviewed and compared to evaluate trends in vulnerability analysis frameworks, emphasizing how adaptive capacity is characterized. Note that this section summarizes and compares the methods and results of previously published studies and are not the author's own work.

BURKE ET AL. (2011)

In “Reefs at Risk Revisited,” Burke et al. (2011) examined the vulnerability of coral reef countries to projected reef loss and degradation. The authors analyzed vulnerability as the combination of: (1) exposure to reef threats, (2) dependence ecosystem services provided by reef communities, and (3) the capacity to adapt to the impacts of reef degradation and loss.

In order to evaluate adaptive capacity, the authors selected indicators that describe human and economic development generally, as well as national-scale indicators specific to reef-dependent regions, as seen in Figure 1.

Table 1. Indicators of adaptive capacity used in Burke et al. (2011).
Table adapted from Burke et al. (2011).

INDICATOR	METRIC
Economic resources	• GDP and remittances per capita
Education	• Adult literacy rate • Combined ratio of enrollment in primary, secondary, and tertiary education
Health	• Average life expectancy
Governance	• Average of World Governance Indicators • Fisheries subsidies that encourage resource conservation and management as a proportion of fisheries value
Access to markets	• Proportion of population within 25 kilometers of market center
Agricultural resources	• Agricultural land area per agricultural worker

The exact calculations of adaptive capacity and vulnerability for this study are unpublished, but the metrics of adaptive capacity were combined to create an overall ranking of adaptive capacity. The rankings for adaptive capacity were incorporated into an overall rank of vulnerability. Burke et al. (2011) reported a selection of results of the vulnerability analysis that highlighted the countries with very high exposure to reef threats, countries with very high reef dependence, and countries with low adaptive capacity, as seen in Table 2.

Table 2. Vulnerability analysis results from Burke et al. (2011).
Table adapted from Burke et al. (2011).

Highest exposure to reef threats	Highest reef-dependence	Lowest adaptive capacity
American Samoa	Antigua and Barbuda	Bangladesh
Anguilla	Bahamas	Cambodia
Antigua and Barbuda	Barbados	China
Aruba	Cook Islands	Djibouti
Bahrain	Curaçao	Egypt
Barbados	Federated States of	Eritrea

	Micronesia	
Bermuda	Fiji	Haiti
British Virgin Islands	French Polynesia	India
Comoros	Grenada	Kenya
Curaçao	Guam	Madagascar
Dominica	Jamaica	Montserrat
Dominican Republic	Kiribati	Mozambique
Grenada	Maldives	Myanmar
Guadeloupe	Marshall Islands	Nauru
Haiti	Mauritius	Nicaragua
Jamaica	Mayotte	Papua New Guinea
Martinique	New Caledonia	Solomon Islands
Mayotte	Palau	Somalia
Nauru	Philippines	Sudan
Northern Mariana Islands	Samoa	Tanzania
Philippines	Solomon Islands	Thailand
Puerto Rico	St. Kitts and Nevis	Timor-Leste
Samoa	St. Lucia	Tokelau
St. Eustatius	Tonga	Tuvalu
St. Kitts and Nevis	Turks and Caicos	Vietnam
St. Lucia	Vanuatu	Wallis and Futuna
Virgin Islands (U.S.)	Wallis and Futuna	Yemen

The results of this study's adaptive capacity analysis indicated that least developed countries have the most limited adaptive capacity, as well as countries with a recent history of conflict (Burke et al. 2011). High levels of economic development and access to resources indicated highest adaptive capacity. Different combinations of the three components of vulnerability created a list of 27 highly vulnerable countries, but the most vulnerable countries, as a result of high exposure and sensitivity and low adaptive capacity, included: Comoros, Fiji, Grenada, Haiti, Indonesia, Kiribati, Philippines, Tanzania, and Vanuatu (Burke et al. 2011).

HUGHES ET AL. (2012)

Hughes et al. (2012) developed an index of vulnerability to declining coral reef fisheries resources in their study entitled, "A framework to assess national level vulnerability from the perspective of food security: The case of coral reef fisheries." The framework combined indicators of (1) exposure to environmental disturbances, (2) sensitivity to change, and (3) adaptive capacity to address change.

Hughes et al. (2012) defined adaptive capacity as, "a country's potential to respond to changes in the contribution of reef fisheries to the food system and ability to take advantage of or mitigate these changes." In this study, vulnerability was calculated for

27 coral reef countries. The list of countries was reduced based on limited data availability for adaptive capacity indicators.

Table 3 provides the list of indicators used in this study. The authors organized the list of indicators into four categories: (1) assets, (2) flexibility, (3) learning, and (4) social organization (Cinner et al. 2009).

Table 3. Indicators of adaptive capacity indicators used in Hughes et al. (2012).
Table adapted from Hughes et al. 2012.

INDICATOR	METRIC
Physical infrastructure	• Percentage of population with access to sanitation
Financial assets	• GDP per capita
Natural assets	• Reef area per capita
Ability to invest in food imports	• Trade balance standardized by GDP per capita
Income inequality	• GINI index
Use of scientific information in fisheries policy	• Scientific robustness
General education level	• Adult literacy rate
Overall quality of fisheries management	• Policy transparency, implementation, use of subsidies, foreign fishing
Overall quality of governance	• Worldwide Governance Indicators
Government effectiveness in fisheries management	• Score indicating mention of fisheries management in national-level policy documents

The study calculated vulnerability as: (Exposure + Sensitivity) - Adaptive Capacity. The study did not apply weights to any of the indicators. Using this calculation, lower scores indicated lower vulnerability to reef resource degradation. Vulnerability scores were standardized; on this scale, zero was the lowest vulnerability score, three was the highest. Table 4 shows the results of the vulnerability analysis.

Table 4. Vulnerability analysis results from Hughes et al. (2012).
Table adapted Hughes et al. (2012).

Country	Exposure	Sensitivity	Adaptive Capacity	Vulnerability
Indonesia	1	0.98	0.37	2.33
Liberia	0.005	0.92	0	1.65
Ivory Coast	0.00025	0.91	0.15	1.48
Kenya	0.016	0.81	0.1	1.45
Philippines	0.88	0.4	0.57	1.43
Honduras	0.019	0.9	0.23	1.41
Cameroon	0.00044	0.91	0.25	1.37

Egypt	0.1	0.97	0.45	1.24
Cambodia	0.00051	0.9	0.43	1.19
Tanzania	0.076	0.94	0.55	1.19
Bangladesh	0	0.88	0.46	1.14
Comoros	0.0067	0.74	0.34	1.12
Nicaragua	0.012	0.89	0.51	1.12
Cape Verde	0.0065	0.86	0.5	1.08
India	0.084	0.44	0.31	0.94
Senegal	0.0015	0.66	0.47	0.92
Madagascar	0.037	0.21	0.063	0.91
China	0.025	0.78	0.65	0.87
Brazil	0.019	0.91	0.78	0.86
Costa Rica	0.014	1	0.89	0.85
Panama	0.025	0.78	0.71	0.82
Mexico	0.038	0.88	0.88	0.75
Trinidad and Tobago	0.0015	0.93	0.91	0.74
Thailand	0.053	0.85	1	0.62
Dominican Republic	0.016	0.39	0.68	0.45
Sri Lanka	0.019	0.12	0.84	0.023
Malaysia	0.083	0	0.8	0

The results from this study demonstrated that no single component or mechanism drives vulnerability to changes in reef fisheries (Hughes et al. 2012). Instead, this study showed that a country's vulnerability is determined by a unique combination of exposure, sensitivity, and adaptive capacity. Adaptive capacity, especially differences in assets and learning, played a significant role in determining vulnerability scores. In terms of overall results, the most vulnerable countries to declines in coral reef fisheries were Indonesia and Liberia, while the least vulnerable were Sri Lanka, Malaysia, and the Dominican Republic (Hughes et al. 2012).

COOLEY ET AL. (2012)

Cooley et al (2012) examined the implications of ocean acidification and human population growth on future global availability protein from mollusks in a study entitled, "Nutrition and income from molluscs today imply vulnerability to ocean acidification tomorrow." In this study, the rankings of vulnerability to decreased mollusk harvests were created using a point scale of "hardship" that aggregated a range of metrics that indicated sensitivity, exposure, and adaptive capacity. The final results of this study are broken down into three subsets: (1) nations with net mollusk export, nations with net mollusk import, and (3) nations with unknown import/export status.

Four main indicators characterized adaptive capacity in this study: (1) income, (2) education, (3) health, and (4) governance. Table 5 displays the metrics used to estimate adaptive capacity.

Table 5. Indicators of adaptive capacity used in Cooley et al. (2012).
Table adapted from Cooley et al. (2012).

INDICATOR	METRIC
Economy	• Gross Domestic Product • Gross Domestic Product per capita adjusted for purchasing power parity
Health	• Life expectancy in years
Education	• Varied per country
Governance	• Worldwide Governance Indicators

National adaptability indices were calculated from the normalized average of the four indicators of adaptive capacity. These normalized averages were then divided into quartiles for each subset of results. Table 6 shows the countries listed in the first quartile of adaptability.

Table 6. Adaptability index for nations ranked in the first quartile with net mollusk export, import, and unknown export/import status from Cooley et al. (2012).
Table adapted from Cooley et al. (2012).

Export	Import	Unknown
Senegal	Solomon Islands	Sierra Leone
Madagascar	Ivory Coast	Kenya
Gambia	Equatorial Guinea	Wallis and Futuna
Mozambique	Sudan	Mauritania
Haiti	Guatemala	US Virgin Islands
Togo	Laos	Syria
Djibouti	Congo, Republic of	Puerto Rico
Eritrea	Liberia	Guadeloupe and Martinique
North Korea	Angola	Serbia-Montenegro
India	Rwanda	American Samoa
Somalia	Zambia	Isle of Man
Yemen	Zimbabwe	Guernsey/Channel Islands
Tanzania	Guinea	Falkland Islands
Pakistan	Malawi	British Virgin Islands
Nigeria	Ghana	-
Cambodia	Uganda	-
Bangladesh	Cameroon	-
Papua New Guinea	Niger	-

Myanmar	Chad	-
Morocco	Nepal	-
-	Iraq	-
-	Swaziland	-

Countries in the first quartile received three points, countries in the second quartile received two points, countries in the third quartile received one point, and countries in the fourth quartile received zero points. Countries that ranked highest in "hardship" points were found to be most vulnerable to the implications of ocean acidification. The final "hardship" scores for top 25 ranked countries are listed in Table 7.

Table 7. Vulnerability of top 20 ranked nations with net mollusk export, import, and unknown export/import status from Cooley et al. (2012).
Table adapted from Cooley et al. (2012).

Export	Import	Unknown
Senegal	Solomon Islands	Sierra Leone
Madagascar	Jamaica	Kenya
Gambia	Belize	Wallis and Futuna
Mozambique	Cook Islands	Mauritania
Haiti	Ivory Coast	US Virgin Islands
Togo	Equatorial Guinea	Syria
Djibouti	Vanuatu	Puerto Rico
Eritrea	Sudan	Guadeloupe and Martinique
North Korea	Guatemala	Serbia-Montenegro
India	Belarus	American Samoa
Somalia	Laos	Isle of Man
Micronesia	Palau	Guernsey/Channel Islands
Nicaragua	Dominican Republic	Falkland Islands
Yemen	Cape Verde	British Virgin Islands
Turks and Caicos Islands	Venezuela	-
Tanzania	Sao Tome and Principe	-
Kiribati	Uruguay	-
Pakistan	Maldives	-
Nigeria	Anguilla	-
Cambodia	Antigua and Barbuda	-

Cooley et al. (2012) ranked a list of 191 countries, with "hardship" points ranging from 7.7 points (indicating the most vulnerable) to 0.6 points (indicating the least vulnerable). The results of the study indicated that vulnerability to the implications of ocean acidification is multi-faceted and countries are considered at risk for different reasons. The results of the analysis demonstrated that a majority of countries with multiple indicators of hardship from declines in mollusk populations are also located in areas where changes in ocean chemistry are expected soonest. Further, countries with significant nutritional and economic dependence on healthy mollusk populations are highly vulnerable to the effects of ocean acidification, regardless of scale (Cooley et al. 2012).

ALLISON ET AL. (2009)

Allison et al. (2009) developed an indicator-based approach to assess vulnerability to climate change impacts in a study entitled, "Vulnerability of national economies to the impacts of climate change on fisheries." The study focused on capture fisheries and calculated vulnerability as a combination of three factors: (1) exposure to physical effects of climate change, (2) sensitivity of both human and ecological systems to change, and (3) adaptive capacity to offset the impacts of climate change (Allison et al. 2009). Table 8 shows the indicators used in this analysis.

Table 8. Indicators of adaptive capacity used by Allison et al. (2009).
Table adapted from Allison et al. (2009).

INDICATOR	METRIC
Health	• Healthy life expectancy
Education	• Literacy rates • School enrollment ratios
Governance	• Political stability • Government effectiveness • Regulatory quality • Rule of law • Voice and accountability • Corruption
Economy	• Total GDP

In this study, adaptive capacity comprised of four indices: (1) healthy life expectancy, (2) education, (3) governance, and (4) economy (Allison et al. 2009). Each of the adaptive capacity metrics, seen in Table 8, were standardized and then averaged to produce an overall score of adaptive capacity.

The study explored several methods of estimating vulnerability, but calculated vulnerability as an un-weighted mean of the standardized indices for exposure, sensitivity, and adaptive capacity (Allison et al. 2009). Data availability limited the number of countries included in the analysis to 132. Higher scores indicate high vulnerability and lower scores indicate lower vulnerability. Table 9 displays the results of the vulnerability analysis.

Table 9. Vulnerability analysis results from Allison et al. (2009).
Table adapted from Allison et al. (2009).

Country	Exposure	Sensitivity	Adaptive Capacity	Vulnerability
Angola	0.74	0.6	0.98	0.77
DR Congo	0.65	0.67	0.94	0.75
Russian Federation	1	0.67	0.52	0.73
Mauritania	0.76	0.59	0.83	0.73
Senegal	0.65	0.74	0.78	0.72
Mali	0.74	0.57	0.85	0.72
Sierra Leone	0.5	0.68	0.96	0.71
Mozambique	0.68	0.59	0.81	0.69
Niger	0.68	0.43	0.97	0.69
Peru	0.82	0.73	0.51	0.69
Morocco	0.74	0.69	0.63	0.69
Bangladesh	0.53	0.8	0.72	0.68
Zambia	0.74	0.54	0.77	0.68
Ukraine	0.91	0.59	0.54	0.68
Malawi	0.71	0.55	0.77	0.68
Uganda	0.62	0.65	0.76	0.68
Zimbabwe	0.88	0.35	0.79	0.67
Cote D'Ivoire	0.56	0.61	0.84	0.67
Yemen	0.68	0.56	0.77	0.67
Pakistan	0.62	0.61	0.76	0.67
Burundi	0.59	0.5	0.91	0.66
Guinea	0.59	0.6	0.8	0.66
Nigeria	0.53	0.65	0.78	0.65
Colombia	0.82	0.59	0.54	0.65
Ghana	0.53	0.76	0.66	0.65
Guinea-Bissau	0.56	0.5	0.88	0.64
Vietnam	0.53	0.85	0.55	0.64
Venezuela	0.79	0.6	0.53	0.64
Algeria	0.82	0.46	0.64	0.64
Cambodia	0.56	0.69	0.67	0.64
United Republic of Tanzania	0.5	0.66	0.75	0.64
Gambia	0.62	0.55	0.73	0.63
Turkey	0.82	0.52	0.55	0.63

As shown in the Table 9, the results of this study indicated that the most vulnerable regions to climate-induced changes in fisheries were Central Africa, northwestern South America, and Asia (Allison et al. 2009). A majority of these most vulnerable countries are also classified as least developed countries and were considered by this study to be doubly dependent upon fish as a food source. The study also found that the most vulnerable countries also play a significant role in fishery exports, producing twenty percent of total fishery exports (Allison et al. 2009).

BECK ET AL. (2012)

The WorldRiskIndex (Beck et al. 2012) assessed disaster risk on at a national scale by combining 28 indicators in four categories: (1) exposure to natural hazards, (2) susceptibility, (3) coping capacities, and (4) adaptive capacities. In this study, vulnerability is calculated as an aggregate of susceptibility, coping capacities, and adaptive capacities.

In this study, coping capacity and adaptive capacity were separated. As defined by the authors of this study, coping capacity indicates a community's ability to minimize negative impacts of and reduce harm from natural hazards. In this study, coping capacity was indicated by: government and authorities, medical services, and material coverage. Adaptive capacity, on the other hand, refers to the measures and strategies available to a community to address the negative impacts of natural hazards, and is indicated by: education, gender equity, environmental status and ecosystem protection, and investment. The indicators used to measure coping capacity are shown in Table 10.

Table 10. Indicators of coping capacity and adaptive capacity used in the WorldRiskIndex (2012). Table adapted from the WorldRiskIndex (2012).

INDICATOR	METRIC
Government and authorities	• Corruption Perceptions Index • Failed States Index
Medical services	• Number of physicians per 10,000 inhabitants • Number of hospital beds per 10,000 inhabitants
Material coverage	• Insurances
Education	• Adult literacy rate • Combined gross school enrollment
Gender equity	• Gender parity in education • Share of female representatives in the National Parliament
Environmental status / ecosystem protection	• Water resources • Biodiversity and habitat protection • Forest management • Agricultural management
Investment	• Public health expenditure • Life expectancy at birth • Private health expenditure

The national-scale coping capacity score was calculated as an aggregation of all the coping capacity indicators, with the following weights: 45 percent for the Corruption Perceptions Index and indicator of good governance; 45 percent for medical services indicators; 10 percent for insurances. Similarly, to calculate a national score for adaptive capacity, the authors weighted each category of indicators equally (25 percent). These scores were then incorporated into the overall assessment of disaster risk, each representing 33 percent of the overall evaluation of disaster risk. Table 11 shows selected results of the WorldRiskIndex's risk analysis.

Table 11. Selected results of the WorldRiskIndex's risk analysis.
Table adapted from Beck et al. 2012.

Highest Risk	Lowest Coping Capacity	Lowest adaptive capacity	Highest Vulnerability
Vanuatu	Afghanistan	Afghanistan	Eritrea
Tonga	Chad	Eritrea	Niger
Philippines	Sudan	Niger	Chad
Guatemala	Haiti	Mali	Afghanistan
Bangladesh	Guinea	Chad	Haiti
Solomon Islands	Myanmar	Haiti	Sierra Leone
Costa Rica	Burundi	Mauritania	Liberia
Cambodia	Central African Republic	Sierra Leone	Mozambique
Timor-Leste	Yemen	Pakistan	Guinea
El Salvador	Iraq	Guinea	Central African Republic
Brunei Darussalam	Niger	Burkina Faso	Ethiopia
Papua New Guinea	Côte d'Ivoire	Liberia	Mali
Mauritius	Guinea-Bissau	Ethiopia	Burundi
Nicaragua	Ethiopia	Comoros	Nigeria
Fiji	Uganda	Benin	Togo

The WorldRiskIndex (2012) limited published results to the top fifteen countries ranked in each component of risk. The study reveals that countries with the lowest coping capacities were concentrated in the continent of Africa, Afghanistan, Myanmar, Yemen, Haiti, and Iraq, with the majority of these low scores driven by lack of effective governance (Beck et al. 2012). In terms of adaptive capacity, the countries with the lowest ability to manage change were concentrated in Southeast Asia, India, West Africa, and Central Africa. As indicated by the components of susceptibility, as well as coping and adaptive capacities, the most vulnerable countries were concentrated in the continent of Africa, with Afghanistan, Haiti, Yemen, Pakistan and Bangladesh (Beck et al. 2012).

STUDY COMPARISON

Several common themes emerge from the comparison of vulnerability analyses. It is important to note that in a majority of methodologies sensitivity is directly associated with a specific type of hazard, like coral reef declines, as in Hughes et al. (2012) and Burke et al. (2011). Adaptive capacity, however, can be defined by generic characteristics of a population, as it is in the WorldRiskIndex, or by information related to a specific type of hazard, as it is in Cooley et al (2012). Despite these differences, each study acknowledges the dynamic, complex and interconnected nature of the mechanisms that drive vulnerability. Each study emphasizes that a country's vulnerability to external stressors is highly unique and influenced by many different factors, each dynamic and interdependent. Table 12 provides a synthesis of the metrics used in each study to measure the adaptive capacity component of vulnerability.

Table 12. Comparison of metrics used to estimate adaptive capacity.
This table compares the metrics used to estimate adaptive capacity in each of the five vulnerability studies explored above.

INDICATOR	Allison et al. (2009)	Hughes et al. (2009)	WorldRiskIndex (2012)	Cooley et al. (2012)	Burke et al. (2011)
ECONOMY	• Total GDP	• GDP per capita; • Trade balance standardized by GDP per capita	• Insurances	• GDP; • GDP per capita adjusted for purchasing power parity	• GDP and remittances per capita; • Proportion of population within 25 kilometers of market center; • Agricultural land area per agricultural worker
HEALTH	• Healthy life expectancy	• N/A	• Life expectancy at birth; • Number of hospital beds per 10,000 inhabitants; • Public health expenditure; • Number of physicians per 10,000 inhabitants; • Private health expenditure	• Average life expectancy	• Average life expectancy
EDUCATION	• Literacy rates; • School enrollment ratios	• Adult literacy rate	• Adult literacy rate; • Combined gross school enrollment	• Varied per country	• Adult literacy rate; • Combined school enrollment ratios

GOVERNANCE	• Worldwide Governance Indicators	• Worldwide Governance Indicators	• Corruption Perceptions Index; • Failed States Index	• Worldwide Governance Indicators	• Worldwide Governance Indicators
INFRASTRUCTURE	• N/A	• Percentage of population with access to sanitation	• N/A	• N/A	• N/A
NATURAL RESOURCE MANAGEMENT	• N/A	• Reef area per capita; • Scientific robustness; • Mention of fisheries management in national-level policy documents; • Policy transparency, implementation; use of subsidies; foreign fishing	• Water resources; • Biodiversity and habitat protection; • Forest management; • Agricultural management	• N/A	• Fisheries subsidies that encourage resource conservation and management as a proportion of fisheries value
EQUITY	• N/A	• Gini Index	• Gender parity in education • Share of female representatives in the National Parliament	• N/A	• N/A

As shown in Table 12, several trends emerge in the characterization of adaptive capacity in vulnerability analyses. The core set of indicators used in all studies included measures of: (1) economy, (2) education, and (3) governance. To estimate economic status, gross domestic product was used in all studies, except the WorldRiskIndex (2012). In terms of education, adult literacy rates were used in all studies, though Allison et al. (2009), Burke et al. (2011), and the WorldRiskIndex (Beck et al. 2012) each augmented their indicator of education with combined school enrollment ratios. The Worldwide Governance Indicators were used by all studies to estimate governance, except the WorldRiskIndex, which used the Corruption Perceptions Index and the Failed States Index to serve as indicators of effective governance. Average life expectancy was used in all studies to indicate the status of health, except Hughes et al. (2012), which did not use any indicator of health.

Several studies included consideration of natural resource management in their analysis of adaptive capacity. Hughes et al. (2009) focused on fisheries policy by analyzing scientific robustness and mention of fisheries in national policies, as policy transparency. The WorldRiskIndex (Beck et al. 2012) incorporated four different metrics of natural resource management that ranged from biodiversity to agricultural management.

In terms of equity, the WorldRiskIndex focused on gender equality in education and governance, while Hughes et al. (2012) focused on gender equity in economic development. Further, only Hughes et al. (2012) considered infrastructure in their investigation of vulnerability.

Using these metrics, each study provided a viable estimation of vulnerability, as well as a characterization of the many components that comprise vulnerability, thereby reducing this complex, theoretical issue into measurable indices that can be used in practical applications. Recent attention has focused on characterizing and measuring vulnerability and adaptive capacity with the objective of directly informing the development and implementation of regionally focused adaptation policies and management strategies (Hughes et al. 2012).

Each analysis considered a different range of countries, though only coral reef countries were included in this comparison for clarity in the context of this project. Table 13 provides a synthesis of vulnerability rankings for coral reef countries from the five studies compared.

Table 13. Comparison of selected vulnerability analysis results.
In order to more clearly compare the results of the five studies, only coral reef countries that were analyzed by three or more studies were included in this table.

Country	Cooley et al. (2012) (Hardship points; high = 7.7; low = 0)	Allison et al. (2009) (High = 1; Low = 0)	Hughes et al. (2012) (High = 2.33; Low = 0)	Burke et al. (2011) (High = 1; Low = 0)	WorldRiskIndex (2012) (%; High = 100; Low = 0)
Bangladesh	5.3	0.68	1.14	0.00	-
Brazil	1.6	-	0.86	0.08	-
Cambodia	5.5	0.64	1.19	0.19	-
China	3.3	-	0.87	0.22	-
Colombia	4.7	0.65	-	0.08	-
Costa Rica	1.7	-	0.85	0.16	-
Dominican Republic	4.6	-	0.45	0.43	-
Egypt, Arab Rep.	3.6	-	1.24	0.21	-
Eritrea	6.5	-	-	0.10	75.35
Haiti	6.6	-	-	1.00	73.54
India	5.7	-	0.94	0.18	-
Indonesia	4.7	-	2.33	0.54	-
Kenya	5.6	-	1.45	0.34	-
Madagascar	7.6	-	0.91	0.53	-
Malaysia	3.3	-	0.00	0.24	-
Mexico	2.6	-	0.75	0.05	-
Madagascar	7.6	-	0.91	0.53	-
Malaysia	3.3	-	0.00	0.24	-
Mexico	2.6	-	0.75	0.05	-
Mozambique	6.6	0.69	-	0.34	71.37
Nicaragua	5.7	-	1.12	0.02	-
Panama	3.6	-	0.82	0.26	-
Philippines	4.6	-	1.43	0.92	-
Sri Lanka	4.7	-	0.02	0.31	-
Tanzania	5.6	0.64	1.19	0.71	-
Thailand	4.6	-	0.62	0.28	-
Venezuela	4.6	0.64	-	0.11	-
Vietnam	4.4	0.64	-	0.42	-
Yemen	5.6	0.67	-	0.30	-

Each study used a different set of metrics to describe vulnerability, and therefore evaluated vulnerability differently, as seen in Table 13. For example, when evaluated, Bangladesh was ranked relatively high in all studies, though Burke et al. (2011) ranked Bangladesh with a score of 0.00, the lowest vulnerability score in the dataset. Burke et al. (2011) ranked Haiti with the highest vulnerability (a score of 1.00), though the rest of the studies scored Haiti with a relatively high vulnerability, it was not evaluated as the highest. Further, Mozambique was ranked relatively high by the Beck et al. (2012), Allison et al. (2009), and Cooley et al. (2012), but ranked relatively low (with a score of 0.34) by Burke et al. (2011).

When considering the vulnerability ranks of Cooley et al. (2012) and Allison et al. (2009), each score is comparable. For example, Cambodia was ranked with 5.5 “hardship” points in Cooley et al. (2012), and Allison et al. (2009) ranked Cambodia as 0.64 on a scale of 0 to 1. This pattern is similar throughout the evaluations; Venezuela, Vietnam, and Yemen were ranked 4.6, 4.4, and 5.6, respectively, by Cooley et al. (2012), and 0.64, 0.64, and 0.67 by Allison et al. (2009).

Comparing Hughes et al. (2012) and Burke et al. (2012), both of which focused on vulnerability as directly related to changes in coral reefs, reveal similarities, as well. For example, Madagascar ranked in the middle of Hughes et al. (2012) with a score of 0.91 on a scale of 0 to 2.33, and ranked in the middle of Burke et al. (2011) with a 0.53 on a scale of 0 to 1.

As presented by Hughes et al. (2012), adaptive capacity is a significant influence on the overall vulnerability ranking. As such, increasing adaptive capacity may provide an opportunity to reduce overall vulnerability to stressors like climate change and ocean acidification. Table 14 provides a synthesis of adaptive capacity rankings for coral reef countries, as derived from the above studies.

Table 14. Comparison of selected results of adaptive capacity analyses.
In order to more clearly compare the results of the five studies, only coral reef countries that were analyzed by three or more studies were included in this table.

Country	Cooley et al. (2011) High = 2; Low = -2	Allison et al. (2009) (High = 0; Low = 1)	Hughes et al. (2012) (High = 1; Low = 0)	Burke et al. (2011) (High = 0; Low = 1)	WorldRiskIndex (2012) (%; High = 0; Low = 100)
Bangladesh	-0.764	0.72	0.46	0.8	-
Brazil	0.194	-	0.78	0.42	-
Cambodia	-0.568	0.67	0.43	0.71	-
China	0.155	-	0.65	0.64	-
Colombia	0.141	0.54	-	0.47	-
Comoros	-	-	0.34	0.53	63.3
Costa Rica	0.51	-	0.89	0.39	-
Dominican Republic	0.066	-	0.68	0.35	-
Egypt	-0.233	-	0.45	0.59	-
Eritrea	-0.809	-	-	0.84	72.68
Haiti	-0.733	-	-	0.66	67.48
Honduras	-0.179	-	0.23	0.53	-
Madagascar	-0.499	-	0.063	0.73	-
Malaysia	0.405	-	0.8	0.43	-
Mexico	0.287	-	0.88	0.43	-
Mozambique	-1.173	0.81		0.9	-
Nicaragua	-0.243	-	0.51	0.56	-
Panama	0.352	-	0.71	0.31	-
Philippines	0.022	-	0.57	0.48	-
Sri Lanka	0.068	-	0.84	0.51	-
Tanzania	-0.592	0.75	0.55	0.76	-
Trinidad and Tobago	0.419	-	0.91	0.42	-
Venezuela	-0.025	0.53	-	0.43	-
Vietnam	-0.061	0.55	-	0.61	-
Yemen	-0.729	0.77	-	0.76	-

Similar to the vulnerability analysis, each study used a different set of metrics to describe adaptive capacity, as seen in Table 12, and therefore evaluated adaptive capacity differently, as shown in Table 14. Some interesting comparisons can be drawn from a review of the five adaptive capacity assessments.

Cooley et al. (2012) ranked Costa Rica, Trinidad and Tobago, Malaysia, and Mexico relatively high in terms of adaptive capacity, while Bangladesh, Eritrea, Haiti, Mozambique and Yemen were ranked with the lowest adaptive capacity of the coral reef countries considered. Similarly, of the countries considered by Allison et al. (2009), Bangladesh, Mozambique, and Yemen were also ranked with the lowest adaptive capacity. Hughes et al. (2012) ranked Bangladesh, Comoros, Egypt, and Honduras with the lowest adaptive capacity in their study, while Burke et al. (2011) ranked Bangladesh, Cambodia, Eritrea, Mozambique, and Yemen with the lowest adaptive capacity. Of the three coral reef countries ranked by the WorldRiskIndex (Beck et al. 2012), Eritrea and Haiti were the lowest.

Costa Rica and Trinidad and Tobago were given the highest adaptive capacity scores by Cooley et al. (2012), while Allison et al. (2009) ranked Colombia, Vietnam and Venezuela with the highest adaptive capabilities. Brazil, Costa Rica, Malaysia, Mexico, and Trinidad and Tobago had the highest adaptive capacity according to Hughes et al. (2012), while Burke et al. (2011) ranked Costa Rica, Dominican Republic, and Panama with the highest adaptive capacity. The WorldRiskIndex (Beck et al. 2012) ranked Comoros with relatively high adaptive capacity.

This comparison provides a detailed investigation at the current state of vulnerability research and analysis. The comparison provides a review of the metrics used to indicate adaptive capacity, demonstrating patterns within and between studies, and highlighting key differences. Some commonalities between adaptive capacity rankings can be seen, like the low rankings given to Mozambique, Bangladesh, Eritrea, and Haiti, and the high rankings given to Costa Rica and Trinidad and Tobago. However, the comparison of all the studies' rankings reaffirm that evaluations of adaptive capacity are highly variable. Each study has different goals, uses different information, and employs different calculation methodologies to assess adaptive capacity. Though the comparison provides a general sense of how each study integrates the components of vulnerability and some general trends can be identified, it is clear that the goals, metrics, and calculations used in assessing vulnerability play a significant role in determining which countries are most (and least) at risk.

DATA COLLECTION AND ANALYSIS

With the information gathered from a comprehensive literature review and a comparison of similar studies, the OA-SESYNC team created a list of seven indicators and twelve metrics to estimate the adaptive capacity of coral reef nations to the effects of ocean acidification: (1) governance; (2) economic means and opportunity; (3) poverty and dependency; (4) education; (5) health; (6) environmental governance; and (7) natural resource management.

The OA-SESYNC team developed a comprehensive list of existing and available datasets that could provide an approximation of each indicator, as seen in Table 15.

Table 15. Adaptive capacity indicators and metrics.
This table provides a list of available datasets that provide an approximation of each indicator.

INDICATORS	AVAILABLE METRICS
Governance	• Worldwide Governance Indicators • Failed States Index
Economic means and opportunity	• Gross Domestic Product per capita • Gini Index
Poverty and dependency	• Population living on less than USD 1.25/day • Watts Index
Education	• Adult literacy rate • Gross enrollment
Health	• Life expectancy
Environmental governance	• Environmental Performance Index
Natural resource management	• Natural Resource Management Index • Fisheries management effectiveness

These metrics are described in Table 16. Appendices C through N provide detailed metadata for each metric, as well as how each dataset was retrieved and manipulated for the purposes of this study.

Table 16. Abbreviated metadata for adaptive capacity metrics.
This table provides brief metadata of each dataset we used to estimate adaptive capacity. More detailed metadata can be found in Appendices C to N of this document.

METRICS	SOURCE	DESCRIPTION
Worldwide Governance Indicators (WGI)	World Bank	The World Bank's Worldwide Governance Indicators synthesize information from 1996-2012 for 215 countries about six broad categories of governance: voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption. For more information, see Appendix K.
Ocean Health Index (OHI) Worldwide Governance Indicators (WGI)	Ocean Health Index	The Ocean Health Index used the Worldwide Governance Indicators to compile a standardized score used to evaluate social resilience. For more information, see Appendix J.
Failed States Index (FSI)	Fund for Peace	As defined by the Fund for Peace, the FSI highlights trends in social, economic, and political pressures, in an annual ranking that aggregates information from twelve indicators. For more information, see Appendix H.
Gross Domestic Product (GDP) per capita	World Bank	As defined by the World Bank, GDP per capita is the gross domestic product divided by the midyear population. For more information, see Appendix C.
Gini Index	World Bank	As defined by the World Bank, the Gini index is a statistical analysis that measures the equity of income distribution of a country's residents. For more information, see Appendix D.
Watts Index	World Bank	As defined by the World Bank, the Watts Index is a distribution-sensitive characterization of poverty. For more information, see Appendix E.
Population living on less than USD 1.25/day	World Bank	To estimate global absolute poverty, the World Bank uses PovCalNet. For more information see Appendix B.
Literacy rate	World Bank	As defined by the World Bank, the average adult literacy rate is calculated by the percentage of the population age 15 and above who can read and write a simple statement about their life. For more information, see Appendix M.
Gross enrollment	World Bank	As defined by the World Bank, the combined gross enrollment indicates the number of students enrolled in primary, secondary, and tertiary education. For more information, see Appendix N.
Life expectancy	World Bank	As defined by the World Bank, the average life expectancy indicates the prevailing patterns of morality at birth. For more information, see Appendix L.
Environmental Performance Index (EPI)	Yale Center for Environmental Law and Policy	Created by the Yale Center for Environmental Law and Policy, the EPI aggregates 20 indicators reflecting national-level environmental data for ecosystem vitality and environmental health. For more information, see

		Appendix G.
Natural Resource Management Index	NASA Socioeconomic Data and Applications Center (SEDAC)	Created by the NASA Socioeconomic Data and Applications Center, the NRMI considers eco-region protection, access to sanitation and water, and child mortality in an overall index to estimate natural resource management. For more information, see Appendix F.
Fisheries management effectiveness	Ocean Health Index Mora et a. 2009.	This metric assesses the effectiveness of fisheries management regimes for several different indicators ranging from scientific robustness to foreign fishing. For more information, see Appendix I.

STATISTICAL ANALYSIS AND RESULTS

Two types of exploratory statistical analyses were completed using the adaptive capacity variables detailed in Table 16: (1) a pair-wise scatter plot matrix, and (2) an exploratory factor analysis. Each dataset was standardized before comparison.

Table 17. List of variables and codes used in statistical analysis.
This table provides the variables and matching codes used in the pair-wise scatter plot matrix and the exploratory factor analysis.

METRICS	CODE
Worldwide Governance Indicators	ZWB_WGI
Ocean Health Index Worldwide Governance Indicators	ZOHI_WGI
Failed States Index	ZFSI
Gross Domestic Product per capita	ZGDP
GINI index	ZGINI
Population living on less than USD 1.25/day	ZPOV
Watts Index	ZWATTS
Adult literacy rate	ZLIT
Gross enrollment	ZENROL
Life expectancy	ZLIFE
Environmental Performance Index	ZEPI
Natural Resource Management Index	ZNRMI
Fisheries management effectiveness	ZMORA

PAIR-WISE SCATTER PLOT MATRIX

With assistance from Ms. Kenady Wilson (Duke University Marine Laboratory), a pair-wise scatter plot matrix was performed using RStudio. A pair-wise scatter plot matrix graphs each variable against one other variable. This kind of analysis is exploratory in nature and does not indicate any sort of causality; rather, a scatter plot reveals relationships and trends between two variables. This information can be used to identify correlations between the variables and can inform further statistical analysis.

RESULTS

Figure 2 shows the results of the pair-wise scatter plot matrix. Each variable in the adaptive capacity dataset was graphed against all other variables separately. The poverty variable, the Watts Index variable and the GINI Index variable were removed from consideration because they lacked data for 41, 44, and 39 of the 80 coral reef countries, respectively. Several interesting trends emerged, as seen in Figure 2 and described below.

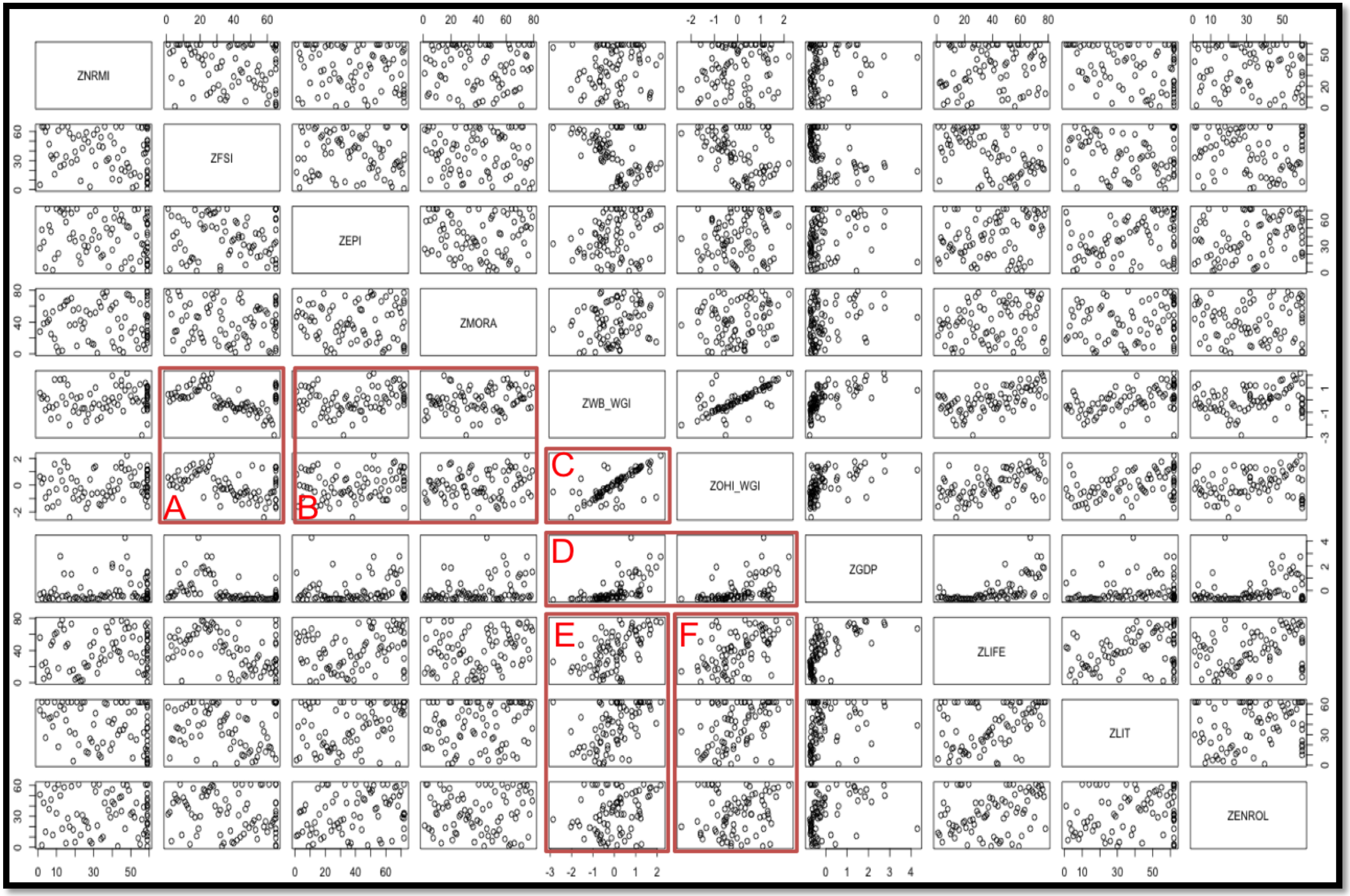

Figure 2. Pair-wise scatter plot matrix results.

This figure shows the pair-wise scatter plot matrix output after removing the datasets for the poverty variable, the Watts Index, and the GINI Index.

Box A: Box A consists of two plots. The top plot graphs the World Bank Worldwide Governance Indicators (ZWG_WGI) against the Failed States Index (ZFSI). The bottom plot graphs the Ocean Health Index's Worldwide Governance Indicators (ZOHI_WGI) against the Failed States Index. A relatively clear negative trend is shown in these plots. This indicates a correlation between the three datasets.

Box B: This box highlights four different scatter plots. The left plots graph the Environmental Performance Index (ZEPI) against the two metrics of Worldwide Governance Indicators (WB_WGI and OHI_WGI), while the right plots graphs the metric of fisheries management effectiveness (ZMORA) against the two metrics of Worldwide Governance Index (WB_WGI and OHI_WGI). A very loose trend is shown between these four datasets.

Box C: A clear positive trend is shown between the two Worldwide Governance Indicators datasets and may indicate that only one of these variables is necessary to include in the analysis of adaptive capacity.

Box D: These plots graph the two metrics of Worldwide Governance Indicators against the metric of GDP (ZGDP). A loosely positive trend is shown in both scatter plots, indicating that as GDP increases, so do the scores for Worldwide Governance Indicators.

Box E: This box highlights trends between the World Bank's Worldwide Governance Indicators (WB_WGI) against the metrics of life expectancy (ZLIFE), literacy (ZLIT), and gross enrollment in school (ZENROL). The plots indicate a positive trend, which may be interpreted as a correlation between these four datasets.

Box F: This box highlights potential correlations between the Ocean Health Index's Worldwide Governance Indicators (OHI_WGI) and the metrics of life expectancy (ZLIFE), literacy (ZLIT), and gross enrollment in school (ZENROL). As seen in Box E, a positive trend is clear.

In addition to the trends that are revealed through the scatter plot matrices, it is important to note the variables that do *not* show a clear trend. This may indicate that the two variables have very different underlying information and are therefore *both* important to include the analysis of adaptive capacity. For example, the scatter plots that compare the Failed States Index (ZFSI), the Environmental Performance Index (ZEPI), and fisheries effectiveness (ZMORA) show no clear trend, as seen in Figure 3.

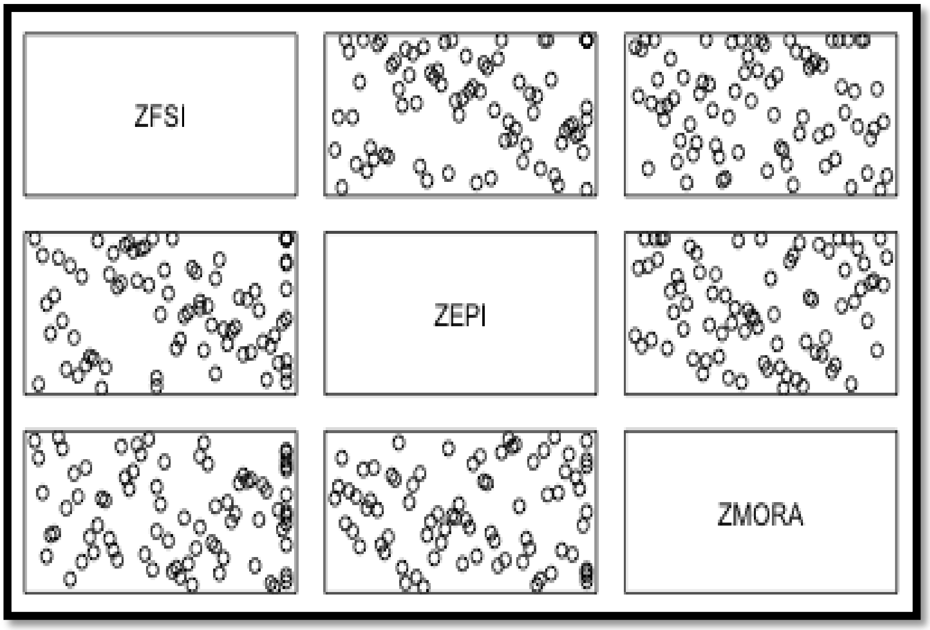

Figure 3. Pair-wise scatter plot matrix of the Failed States Index (ZFSI), the Environmental Performance Index (ZEPI), and fisheries management effectiveness (ZMORA).
This scatter plot matrix shows no clear trend and could indicate that all three variables are important to consider in the overall characterization of adaptive capacity.

It is important to note that the pair-wise scatter plot matrices above provide an initial overview of the variables and how they are (or are not) related. Further analysis will be required to confirm or deny correlation more precisely.

EXPLORATORY FACTOR ANALYSIS

With assistance from Dr. Betsy Albright (Nicholas School of the Environment) a principal components analysis was completed in STATA using the adaptive capacity variables shown in Table 16. Exploratory factor analyses provide information needed to reduce and summarize the data tested (UCLA Statistical Consulting Group). A factor analysis seeks to identify the underlying unobservable variables that are reflected in the observed variables (UCLA Statistical Consulting Group**)**. This information can be used to explore the underlying structure of a series of variables. The factor analysis is based on the correlation matrix of the variables, but unlike the pair-wise scatter plot matrix, a factor analysis considers all the variables in a dataset together all at once. This kind of statistical analysis breaks down the correlation matrix into factors, so that the variables binned within the same factor are more highly correlated with each other than with variables in the other factors (UCLA Statistical Consulting Group). In this analysis, it is assumed that variables that are correlated (or binned together) share one or more of the same underlying causes or drivers.

RESULTS

The following tables and figures display the results from the unrotated principal components factor analysis performed using the adaptive capacity variables. Three factors were retained from the 37 observations considered. 27 parameters were included.

As shown in Table 18, the first three factors of the analysis contained approximately 75.8 percent of the variables. The Eigenvalue gives the variance of the factor. As shown in Table 18, the first factor accounts for the most variance. The proportion gives the proportion of variance in the factor, while the cumulative provides the cumulative proportion of variance by the factors (UCLA Statistical Consulting Group).

Table 18. Principal component factor analysis results.

FACTOR	EIGEN VALUE	PROPORTION	CUMULATIVE
1	5.31538	0.5315	0.5315
2	1.23999	0.1240	0.6555
3	1.03066	0.1031	0.7586
4	0.84876	0.0849	0.8435
5	0.43863	0.0439	0.8873
6	0.37367	0.0374	0.9247
7	0.28799	0.0288	0.9535
8	0.23009	0.0230	0.9765
9	0.16938	0.0169	0.9935
10	0.06545	0.0065	1.0000

Table 19 provides the factor loadings and unique variances for each variable included in the analysis. Factor loadings demonstrate how each variable is weighted in each factor. This indicates a correlation between the variables binned within the same factor.

Table 19. Principal component analysis factor loadings and unique variances.

VARIABLE	FACTOR 1	FACTOR 2	FACTOR 3	UNIQUENESS
ZNRMI	0.3096	-0.7642	-0.0396	0.3186
ZFSI	-0.9344	0.0693	-0.0234	0.1216
ZEPI	0.6130	0.5853	-0.0605	0.2781
ZMORA	0.1657	0.1960	0.9347	0.0791

ZWB_WGI	0.9084	-0.0944	0.0027	0.1659
ZWGI_OHI	0.8082	-0.2127	-0.0075	0.3016
ZGDP	0.7214	-0.2120	0.2659	0.3639
ZLIFE	0.8615	-0.0119	0.0125	0.2575
ZLIT	0.7249	0.4117	-0.2753	0.2292
ZENROL	0.8226	0.0395	-0.1521	0.2986

Figure 3 shows a conceptual map of the factor loadings for the adaptive capacity variables shown in Table 19. This information provides a succinct assessment of the underlying structure of the variables the OA-SESYNC team proposes to use to evaluate national-scale adaptive capacity to the effects of ocean acidification.

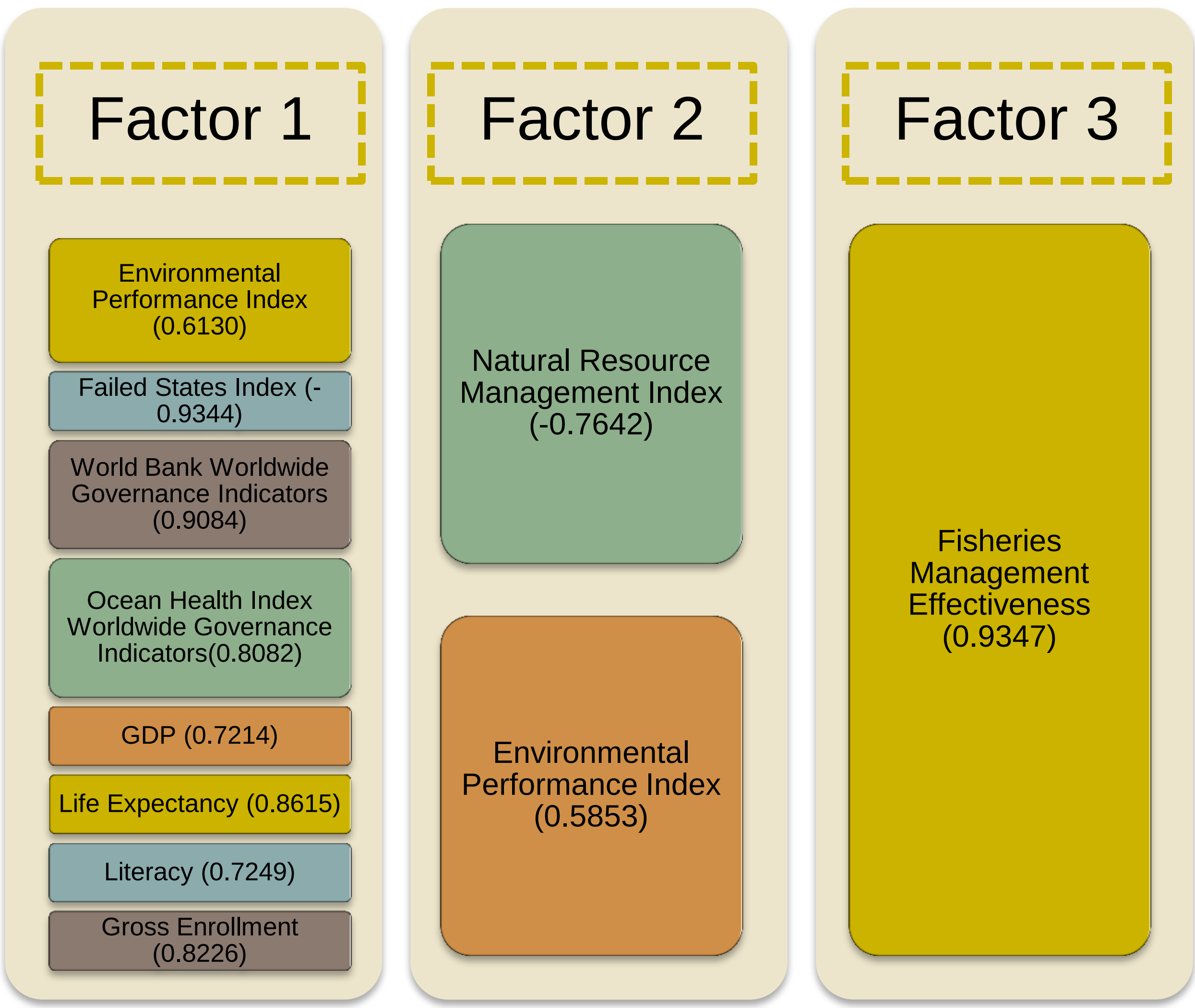

Figure 4. Principal components factor analysis results.

As shown, Factor 1 contains a clear majority of the variables. This implies that these variables have similar drivers and are correlated. It is important to note, however, that the Failed States Index is negatively loaded in Factor 1.

Another important result from the analysis is that the fisheries management effectiveness metric is the only metric loaded in Factor 3. This may indicate that the fisheries management effectiveness metric is highly un-correlated with the rest of the variables and should therefore be included in the final evaluation of adaptive capacity.

Similarly, the Environmental Performance Index and the Natural Resource Management Index are binned together in Factor 2. This indicates that the two variables have similar underlying structures and are correlated. However, it is important to note that the Natural Resource Management Index is negatively loaded in Factor 2, while the Environmental Performance Indicator is positively loaded in Factor 2.

Though further statistical analysis is necessary to identify correlations more precisely, the information presented in these statistical analyses can be used by the OA-SESYNC team to reduce the number of metrics and indicators used to evaluate adaptive capacity to the effects of ocean acidification. Clearly, the metrics of fisheries management effectiveness should be included, as well as, one or both of the metrics of natural resource management. The data of the variables binned in Factor 1 have similar underlying structures and can therefore be reduced or synthesized according to the goals and objectives of the larger project.

CONCLUSION

This Master's Project contributes to the goals and objectives of a larger project that explores ocean acidification at a much broader scope. The ultimate goal of the OA-SESYNC project seeks to fill gaps in scientific research through an interdisciplinary, data-driven vulnerability assessment. The OA-SESYNC approach integrates oceanographic, biological, and socioeconomic data to identify two types of potential "hotspots": (1) biological hot-spots, where ocean acidification is likely to take a high toll on economically important species, and (2) socio-economic hot-spots, where human communities are likely to suffer impacts from the biological effects of ocean acidification.

The statistical analyses performed on the adaptive capacity variables provides the OA-SESYNC team with the information needed to explore and analyze the relationships between the variables and the underlying structure of the entire adaptive capacity dataset. Understanding these trends and correlations, as well as the underlying structure of the data, helps evaluate how each coral reef country measures up in terms of adaptive capacity - and ultimately vulnerability - to ocean acidification. This information will inform further analysis of the adaptive capacity variables, as well as provide a succinct justification for our final selection of variables for estimating adaptive capacity and vulnerability. This information will also directly inform future vulnerability frameworks and create a methodology for gathering, synthesizing, and analyzing similar types of data.

NEXT STEPS

In identifying these biological and socioeconomic hotspots, the OA-SESYNC project will highlight places where communities might benefit from adaptive measures to reduce predicted impacts of ocean acidification. Policy decisions and management strategies must be informed by integrated, locally relevant data and analysis in order to create effective, site-specific adaptive management plans. An ocean acidification "hot-spot" analysis that synthesizes oceanographic, ecological, economic, and social data can effectively highlight key regions where communities can benefit most from adaptive measures to reduce impacts of projected ocean acidification.

Spatially prioritizing research and management efforts is particularly critical when considering the limited resources available to dedicate to research, analysis, and adaptive management plans. The project results will be shared in an interactive web-based mapping program, developed by Dr. Will McClintock, a principal investigator for the project. The information provided will not only serve as an impetus for focusing mitigation and adaptation efforts, but the project will also identify and analyze gaps in current knowledge with the objective of informing future vulnerability assessments and supporting effective, site-specific adaptation to the impacts of ocean acidification.

The effects of ocean acidification are not limited to ecological communities. Human communities that depend on healthy, balanced marine and coastal ecosystems to sustain their livelihoods are inextricably connected to the process of ocean acidification. Human vulnerability and adaptive capacity are complex forces driven by a range of dynamic mechanisms, but characterizing and measuring their impact is possible. Identifying the degree to which the ecological impacts of ocean acidification will affect human communities is a critical step in moving towards focused and actionable policies. Layering biological data with available data about human vulnerability can provide an integrated, locally relevant analysis to inform site-specific adaptive management plans.

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APPENDICES

A: CORAL REEF COUNTRIES

The *World Atlas of Coral Reefs*, as prepared by the United Nations Environment Programme World Conservation Monitoring Centre (2001, provides a list of the eighty countries with coral reefs. It should be noted that France (FRA), the Netherlands (NLD), New Zealand (NZL), Great Britain (GBR), and the United States of America (USA) include territories and freely associated states.

This spreadsheet, adapted from Spalding & Green (2001), lists the country and associated three letter country code.

Source: Spalding MD, Ravilious C, Green EP (2001) *World Atlas of Coral Reefs*. University of California Press, Berkeley, USA.

Country Code	Country
ATG	Antigua and Barbuda
AUS	Australia
BHS	Bahamas, Commonwealth of the
BHR	Bahrain, State of
BGD	Bangladesh, Peoples Republic of
BRB	Barbados
BLZ	Belize
BRA	Brazil, Federative Republic of
BRN	Brunei Darussalam
KHM	Cambodia
CHN	China
COL	Colombia
COM	Comoros, Islamic Federal Republic of
CRI	Costa Rica, Republic of
CUB	Cuba, Republic of
DJI	Djibouti, Republic of
DMA	Dominica, Commonwealth of
DOM	Dominican Republic
ECU	Ecuador, Republic of
EGY	Egypt, Arab Republic of
ERI	Eritrea
FJI	Fiji, Republic of
FRA	France Including: Clipperton, Mayotte, Réunion, Guadeloupe, Martinique, New Caledonia, French Polynesia, Wallis and Futuna Islands

GRD	Grenada
HTI	Haiti, Republic of
HND	Honduras, Republic of
WSM	Independent State of Western Samoa
IND	India, Republic of
IDN	Indonesia, Republic of
IRN	Iran, Islamic Republic of
ISR	Israel, State of
JAM	Jamaica
JPN	Japan
JOR	Jordan, Hashemite Kingdom of
KEN	Kenya, Republic of
KIR	Kiribati
KWT	Kuwait, State of
MDG	Madagascar, Republic of
MYS	Malaysia
MDV	Maldives, Republic of
MHL	Marshall Islands, Republic of the
MUS	Mauritius, Republic of
MEX	Mexico
FSM	Micronesia, Federated States of
MOZ	Mozambique, Republic of
MMR	Myanmar, Union of
NRU	Nauru, Republic of
NLD	Netherlands Including: Aruba, Netherlands Antilles
NZL	New Zealand Including: Cook Islands, Niue, Tokelau
NIC	Nicaragua, Republic of
OMN	Oman, Sultanate of
PLW	Palau, Republic of
PAN	Panama, Republic of
PNG	Papua New Guinea
PHL	Philippines, Republic of the
QAT	Qatar, State of
KNA	Saint Kitts and Nevis
LCA	Saint Lucia
VCT	Saint Vincent and the Grenadines
SAU	Saudi Arabia, Kingdom of
SYC	Seychelles, Republic of
SGP	Singapore, Republic of
SLB	Solomon Islands

SOM	Somali Democratic Republic
LKA	Sri Lanka, Democratic Socialist Republic of
SDN	Sudan, Republic of the
TWN	Taiwan, Province of China
TZA	Tanzania, United Republic of
THA	Thailand, Kingdom of
TON	Tonga, Kingdom of
TTO	Trinidad and Tobago, Republic of
TUV	Tuvalu
ARE	United Arab Emirates
GBR	United Kingdom Including: British Indian Ocean Territory, Anguilla, Bermuda, Cayman Islands, Pitcairn, Turks and Caicos Islands, British Virgin Islands
USA	United States of America Including: Florida and Gulf of Mexico, Hawaii, United States Minor Outlying Islands, American Samoa, Puerto Rico, US Virgin Islands, Guam, Northern Mariana Islands
VUT	Vanuatu, Republic of
VEN	Venezuela, Republic of
VNM	Viet Nam, Socialist Republic of
YEM	Yemen, Republic of

B: POVERTY HEADCOUNT RATIO (%)

ADAPTIVE CAPACITY
Wealth/Poverty
METRIC: Poverty Headcount Ratio (%)
SOURCE: World Bank. (2014). Poverty Headcount Ratio. Data retrieved from World DataBank: World Development Indicators database.
DESCRIPTION: As defined by the World Bank, the "poverty estimates combine the Purchasing Power Parity (PPP) exchange rates for household consumption from the 2005 International Comparison Program with data from more than 850 household surveys across 127 developing countries. Over two million randomly sampled households were interviewed for the 2010 estimate, representing 85 percent of the population of the developing world." Further, "PovcalNet was developed for the sole purpose of public replication of the World Bank's poverty measures for its widely used international poverty lines, including $1.25 a day and $2 a day." As noted by the World Bank, this information cannot be directly compared with national-scale poverty rates, which are created with country-specific poverty lines using local currencies. The database is updated every three years.
SCALE: National government, only low- and middle-income countries
Data retrieved from: http://iresearch.worldbank.org/PovcalNet/index.htm?1
Data manipulation methods: 1. Use "Replicate the World Bank's regional aggregation" tab 2. Choose 2010 as year in right-hand box 3. Use "38" as poverty line in right-hand box 4. Submit 5. Click "Show all countries info" 6. Copy/paste table into Excel spreadsheet 7. Deleted columns: None. 8. Deleted rows: a. China - Rural b. China - Urban c. India - Rural d. India - Urban e. Indonesia - Rural f. Indonesia - Urban 9. Added columns: Country Code 10. Added rows: None.

C: GROSS DOMESTIC PRODUCT

ADAPTIVE CAPACITY
Wealth/Poverty
METRIC: Gross Domestic Product (GDP) per capita
SOURCE: World Bank. (2014). Gross Domestic Product per capita. Data retrieved from World DataBank: World Development Indicators database.
DESCRIPTION: As defined by the World Bank (2014), “GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars.”
SCALE: National government
Data retrieved from: http://data.worldbank.org/indicator/NY.GDP.PCAP.CD
Data manipulation methods: 1. Downloaded as Excel file. 2. Deleted columns: None. 3. Added columns: None. 4. Deleted rows: Regional aggregations, etc. - Kept only the individual country statistics. 5. Added rows: None.

D: GINI INDEX

ADAPTIVE CAPACITY
Wealth/Poverty
METRIC: Gini Index
SOURCE: World Bank. (2014). Gini Index. Data retrieved from World DataBank: World Development Indicators database.
DESCRIPTION: As defined by the World Bank (2014), the "Gini index measures the extent to which the distribution of income or consumption expenditure among individuals or households within an economy deviates from a perfectly equal distribution. A Lorenz curve plots the cumulative percentages of total income received against the cumulative number of recipients, starting with the poorest individual or household. The Gini index measures the area between the Lorenz curve and a hypothetical line of absolute equality, expressed as a percentage of the maximum area under the line. Thus a Gini index of 0 represents perfect equality, while an index of 100 implies perfect inequality."
SCALE: National government
Data retrieved from: http://data.worldbank.org/indicator/SI.POV.GINI
Data manipulation methods: 1. Downloaded as Excel file. 2. Deleted columns: None. 3. Added columns: None. 4. Deleted rows: Regional aggregations - Kept only individual country statistics. 5. Added rows: None.

E: WATTS INDEX

ADAPTIVE CAPACITY
Wealth/Poverty
METRIC: Watts Index
SOURCE: World Bank. (2014). Watts Index. Data retrieved from World DataBank: World Development Indicators database.
DESCRIPTION: The Watts Index was developed in 1958 and is considered the first distribution-sensitive measure of poverty.
SCALE: National government
Data retrieved from: http://iresearch.worldbank.org/PovcalNet/index.htm?1
Data manipulation methods: 1. Downloaded as Excel file. 2. Deleted columns: None. 3. Added columns: None. 4. Deleted rows: Regional aggregations - Kept only individual country statistics. 5. Added rows: None.

F: NATURAL RESOURCES MANAGEMENT INDEX

ADAPTIVE CAPACITY
Environmental Governance
METRIC: Natural Resources Management Index (NRMI)
SOURCE: Center for International Earth Science Information Network – CIESIN – Columbia University. 2011. Natural Resource Management Index (NRMI), 2011 Release. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.79927/H45Q4T1N.
DESCRIPTION: As defined by the Center for International Earth Science Information Network and the NASA Socioeconomic Data and Applications Center (2011), “the NRMI is a composite index for 174 countries derived from the average of four proximity-to-target indicators for (1) eco-region protection (weighted average percentage of biomes under protected status), (2) access to improved sanitation, (3) access to improved water and (4) child mortality.”
SCALE: National government
Data collection methods: 1. Website: http://sedac.ciesin.columbia.edu/data/collection/nrmi/sets/browse
Data manipulation methods: 1. Downloaded Natural Resource Management Index (2011 release) as Excel spreadsheet 2. Added columns: 1. *ND (no data) for blank spaces 2. Deleted columns: None 3. Added rows: None 3. Deleted rows: None

G: ENVIRONMENTAL PERFORMANCE INDEX

ADAPTIVE CAPACITY
Environmental Governance
METRIC: Environmental Performance Index (EPI)
SOURCE: Hsu, A., J. Emerson, M. Levy, A. de Sherbinin, L. Johnson, O. Malik, J. Schwartz, and M. Jaiteh. (2014). The 2014 Environmental Performance Index. New Haven, CT: Yale Center for Environmental Law and Policy.

DESCRIPTION: According to Hsu et al. (2014), "the Environmental Performance Index calculates national level scores that rank countries based on environmental public health- and ecosystem vitality-based performance indicators to evaluate countries' achievement of established environmental policy objectives."
 	
The EPI Framework Structure is organized into two objectives with underlying indicators, as described below.
Objectives:
1. Environmental Health
    a. Environmental burden of disease
        i. Child mortality
    b. Air pollution (effects on humans)
        i. Indoor air pollution
        ii. Particulate matter
    c. Water (effects on humans)
        i. Access to drinking water
        ii. Access to sanitation
2. Ecosystem Vitality
    a. Air Pollution (effects on ecosystem)
        i. Sulfur dioxide emissions per capita
        ii. Sulfur dioxide emissions per GDP
    b. Water (effects on ecosystem)
        i. Change in water quality
    c. Biodiversity & habitat
        i. Biome protection
        ii. Marine protection
        iii. Critical habitat protection
    d. Agriculture
        i. Agricultural subsidies
        ii. Pesticide regulation
    e. Forestry
        i. Growing stock change
        ii. Forest loss
        iii. Forest cover change
    f. Fisheries
        i. Fishing stocks overexploited

ii. Coastal shelf fishing pressure g. Climate Change i. CO2 per capita ii. CO2 per GDP iii. CO2 emissions per electricity generation iv. Renewable electricity
SCALE: National government
Data retrieved from: http://epi.yale.edu/downloads
Data manipulation methods: 1. Copied/pasted “Table of Main Results” into Excel spreadsheet 2. Added columns a. Country code (adm0_a3_is) 3. Deleted columns: None 4. Added rows: None 5. Deleted rows: None 6. Added information for the following countries from the 2014 Environmental Performance Index. a. Antigua and Barbuda (ATG) b. Bahamas (BHS)

H: FAILED STATES INDEX

ADAPTIVE CAPACITY
Governance
METRIC: The Failed States Index (FSI)
SOURCE: The Fund for Peace (2012). The Failed States Index.
DESCRIPTION: The Failed States Index, as defined by the Fund for Peace (2012), highlights annual trends in social, economic and political pressures that affect all states, but can strain some beyond their capacity to cope. As defined by the Fund for Peace (2012), the FSI is "based on the twelve primary social, economic and political indicators of the Conflict Assessment Software Tool (CAST) methodology, developed by The Fund for Peace. The Fund for Peace's software performs content analysis to separate the relevant data from the irrelevant. Using various algorithms, this analysis is then converted into a score representing the significance of each of the various pressures for a given country." Indicators used include: 1. Social a. Demographic pressures b. Refugees and IDPs c. Group grievance d. Human flight and brain drain 2. Economic a. Uneven economic development b. Poverty and economic decline 3. Political and Military a. State legitimacy b. Public services c. Human rights and rule of law d. Security apparatus e. Factionalized elites f. External intervention"
SCALE: National government
Data retrieved from: http://ffp.statesindex.org/rankings
Data manipulation methods: 1. Downloaded 9th (2013) rankings as Excel spreadsheet 2. Added columns: Country code (adm0_a3_is) 3. Deleted columns: None. 4. Added rows: None. 5. Deleted rows: None.

I: FISHERIES MANAGEMENT EFFECTIVENESS

ADAPTIVE CAPACITY
Fisheries Management
METRIC: Fisheries management effectiveness
SOURCE: Mora, C., Myers, R. A., Coll, M., Libralato, S., Pitcher, T. J., Sumaila, R. U., … Worm, B. (2009). Management effectiveness of the world's marine fisheries. *PLoS Biology*, *7*(6), e1000131. doi:10.1371/journal.pbio.1000131
DESCRIPTION: Mora et al. (2009) assessed the current effectiveness of fisheries management regimes for Scientific Robustness, Policy Transparency, Implementation Capacity, Subsidies, Fishing Effort, and Foreign Fishing. In this assessment, all countries with coastal areas were assessed through a combination of surveys, empirical data and enquiries to fisheries experts. For each reporting region in the Ocean Health Index, Mora et al.'s scores for each category were rescaled to 0 and 1, scaling the maximum possible value for each category as 1. For each country or reporting region, scores for all 6 categories were averaged to produce an overall score of Fisheries Management Effectiveness.
SCALE: National government
Data retrieved from: http://www.oceanhealthindex.org/Components/Fisheries_Management_Effectiveness ftp://ohi.nceas.ucsb.edu/pub/data/2012/index.html
Data manipulation methods: 1. Downloaded as Excel .csv spreadsheet - ftp://ohi.nceas.ucsb.edu/pub/data/2012/layers/7_21_mora_et_al_2009.csv 2. Also downloaded Regions_Countries from ftp://ohi.nceas.ucsb.edu/pub/data/2012/regions/regions_countries.csv as Excel .csv file 3. Match Region_ID and Resilience_Score with Region_ID and Country_Name 4. Added columns: a. ISO Alpha-3 b. *ND (no data) for blank spaces 5. Deleted columns: None. 6. Added rows: None. 7. Deleted rows: None.

J: OCEAN HEALTH INDEX WORLDWIDE GOVERNANCE INDICATORS

ADAPTIVE CAPACITY
Governance
METRIC: Ocean Health Index (OHI) World Governance Indicators (WGI)
SOURCE: Halpern, B. S., Longo, C., Hardy, D., McLeod, K. L., Samhouri, J. F., Katona, S. K., … Zeller, D. (2012). An index to assess the health and benefits of the global ocean. *Nature*, *488*(7413), 615–20. doi:10.1038/nature11397
DESCRIPTION: As defined by the Ocean Health Index, "Data for WGI (are gathered through surveys and other evaluations conducted in collaboration with more than 30 international organizations, including information from individuals, non-governmental organizations (NGOs), think tanks, aid donors, public officials and corporations doing business in the countries being assessed. The resulting data (more than 40 different data layers) are used to evaluate six dimensions of governance: Voice and Accountability, Political Stability and Absence of Violence, Government Effectiveness, Regulatory Quality, Rule of Law and Control of Corruption. WGI is updated annually. WGI scores each dimension from approximately -2.5 to 2.5. The Ocean Health Index rescaled those scores to a range of 0 to 1, then averaged the six rescaled scores to produce a single WGI score (range 0 to 1) for each country. The full composite score for all six WGI indicators was used to evaluate social resilience for all Ocean Health Index goals, with the exception of Livelihoods."
SCALE: National government
Data retrieved from: http://www.oceanhealthindex.org/Components/World_Governance_Indicators_WGI
Data manipulation methods: 1. Downloaded from **ftp://**ohi.nceas.ucsb.edu/pub/data/2012/index.html as Excel .csv spreadsheet **–** **ftp://**ohi.nceas.ucsb.edu/pub/data/2012/layers/7_70_srcdata_wgi.csv 2. Also need to download Country Codes from **ftp://**ohi.nceas.ucsb.edu/pub/data/2012/regions/countries.csv as Excel .csv file 3. Match Country Codes to Country Names 4. Added columns: a. ISO Alpha-3 5. Deleted columns: None 6. Added rows: None. 7. Deleted rows: None.

K: WORLDWIDE GOVERNANCE INDICATORS

ADAPTIVE CAPACITY
Governance
METRIC: Worldwide Governance Indicators (WGI)
SOURCE: Kaufmann, D., Kraay, A., & Mastruzzi, M. (2010). The Worldwide Governance Indicators Project.
DESCRIPTION: According to Kaufmann, Kraay, and Mastruzzi (2010), "The Worldwide Governance Indicators report on six broad dimensions of governance for over 200 countries over the period 1996-2011: 1. **Voice and accountability**: captures perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media 2. **Political stability and absence of violence:** measures perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including politically-motivated violence and terrorism 3. **Government effectiveness:** captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. 4. **Regulatory quality**: captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development 5. **Rule of law**: captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence 6. **Control of corruption**: captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests The WGI are composite governance indicators based on 30 underlying data sources that are rescaled and combined to create the six aggregate indicators using an unobserved components model. "
SCALE: National government
Data retrieved from: http://info.worldbank.org/governance/wgi/index.asp
Data manipulation methods: 1. Downloaded as Excel spreadsheet 2. Added columns: a. "AVERAGE" column - average the 2011 scores for each country's Voice and accountability, Political stability and absence of violence, Government

effectiveness, Regulatory quality, Rule of law, and Control of corruption scores.

   b. adm0_a3_is

3. Deleted columns: None.
4. Added rows: None.
5. Deleted rows: Regional aggregations, etc. - Kept only the individual country statistics.

L: LIFE EXPECTANCY

ADAPTIVE CAPACITY
Health
METRIC: Life Expectancy
SOURCE: World Bank. (2014). Life expectancy at birth, total (years). Data retrieved from World DataBank: World Development Indicators database.
DESCRIPTION: According to the World Bank (2014), "life expectancy at birth indicates the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life."
SCALE: National government
Data retrieved from: http://data.worldbank.org/indicator/SP.DYN.LE00.IN
Data manipulation methods: 1. Downloaded as Excel file. 2. Added columns: None. 3. Deleted columns: None. 4. Added rows: None a. *ND (no data) for blank spaces. 5. Deleted rows: Regional aggregations - Kept only individual country statistics.

M: LITERACY RATE

ADAPTIVE CAPACITY
Education
METRIC: Literacy Rate
SOURCE: World Bank. (2014). Adult (15+) literacy rate (%). Data retrieved from World DataBank: World Development Indicators database.
DESCRIPTION: As defined by the World Bank (2014), the average adult literacy rate is calculated as a percentage of a country's population age 15 and above who can read and write a short statement about their everyday life. Literacy also incorporates numeracy, which is defined as the ability to make simple arithmetic calculations.
SCALE: National government
Data retrieved from: http://data.worldbank.org/indicator/SE.ADT.LITR.ZS
Data manipulation methods: 1. Downloaded as Excel file. 2. Deleted columns: None. 3. Added columns: a. Average Literacy Rate (%) = average the percentages over the time period of 1970 to 2012 b. *ND (no data) for blank spaces 4. Deleted rows: Regional aggregations - Kept only individual country statistics. 5. Added rows: None.

N: COMBINED GROSS ENROLLMENT

ADAPTIVE CAPACITY
Education
METRIC: Combined Gross Enrollment
SOURCE: UNESCO Institute for Statistics (2012). Combined gross enrolment in education (both sexes) (%). Data Centre.
DESCRIPTION: According to the UNESCO Institute for Statistics, "the combined gross enrollment in education (both sexes) indicates the number of students enrolled in primary, secondary, and tertiary education, regardless of age. This data is listed as a percentage of the population of theoretical school age for the three levels."
SCALE: National government
Data retrieved from: https://data.undp.org/dataset/Combined-gross-enrolment-in-education-both-sexes-/jbhn-xkjv

Data manipulation methods:
1. Downloaded as Excel spreadsheet
2. Added columns:
    a. "AVERAGE" column - average the percentages over the time period of 2000 to 2011
    b. adm0_a3_is
    c. *ND (No Data) for blank spaces
3. Deleted columns: None.
4. Added rows: None.
5. Deleted rows: None.